PART III

The Continuum Theory

I. Introduction

The observations presented can be explained in a more or less satisfactory manner in terms of colloidal chemistry, as long as we are dealing with the particles as a whole. But all the reactions described are but outward manifestations, consequences of changes inside the particles. In explaining changes inside molecules we have to be led by chemical concepts, but classical chemical concepts fail to give us any lead.

This failure is not limited to muscular contraction. Discounting a few cases of electron- or H-transfer we are unable to explain any biological reaction. The biochemist, by means of his active substances, like hormones, vitamins, or physiological or pharmacological agents, is capable of setting off the most astounding biological reactions, but if asked about the molecular mechanism of these reactions he will have to confess his complete ignorance. Not only are we unable to explain these reactions by means of our chemical concepts, but we can state that the properties of living matter, to which these amazing biological reactions are due, are not expressed in our chemical symbols and are thus not taken account of in our theory of matter. A phenanthrene, for instance, acting as sex hormone, is, according to its chemical formula, a perfectly stable compound and so is the polypeptide chain of the protein, which the hormone probably acts upon. Judged by their chemical formula, both require a rather drastic chemical treatment in order to be made to react. In the body they react spontaneously at low temperature. The same holds true for other biological agents, most of which are, chemically, perfectly stable. This failure to explain biological reactions suggests that our basic theory of the structure of living matter is inadequate. This theory finds expression in our structural formulae in which each atom is denoted by a special symbol. The theory could be summed up by saying that living matter, like other substances, is built of molecules, the molecules of discrete atoms, each atom consisting of a nucleus and the surrounding electrons. Each nucleus has its electrons

and each electron belongs to a nucleus, only valency electrons being shared by neighboring atoms. (In exceptional cases, as that of conjugated double bonds, single electrons are shared by a greater number of atoms.)

The study of electric conductivity of metals has led to a new idea of the structure of matter which explains electric conductivity by the pooling of valency electrons. In this theory the energy-terms of the single valency electrons fuse to common, quasi-continuous bands. Thus the single electron ceases to be, so to say, the private property of an atom but belongs to the whole system in which it is capable of moving more or less freely. This concept has since been extended to dielectrics, which might have such a continuous band-spectrum without being conductors.* Whether a substance is a conductor or not does not depend solely on whether it has a continuous band-spectrum but also depends on the number of electrons within this band. Any band contains N terms if N is the number of unit-cells taking part in the formation of that band. The Pauli exclusion principle does not allow more than two electrons (of opposite spin) to occupy the same level; so if the number of valency electrons in the single atoms is odd, then only half the terms will be occupied in the highest band and half will be free; if the number is even, then all terms will be occupied. In the first case the system will be a conductor, in the last, an insulator, because for every electron moving in any direction there will be another moving in the opposite direction.

The single bands or "zones" are separated by forbidden zones. If the forbidden zones are narrow, heat agitation may suffice to raise an electron from the highest filled band into the next higher, empty zone, making the substance a "semi-conductor."

In order to be able to develop band spectra, the atoms or other units taking part in the building of that system must comply with certain demands. First, there must be a certain, rather large number of them. Second, their energy-terms must not be too different. Third, they must not be too far apart

*An admirably clear summary is given by Seitz and Johnson in the *J. Appl. Physics* (1937). *8*, 84, 156, 260.

in space and must be arranged according to a pattern with very high regularity, a condition fulfilled in crystals.

It occurred to me several years ago that if this theory of matter could be applied to living structures, we might be able to explain biological reactions. For instance, if we could look upon a protein particle as upon a formation in which electrons are shared by the whole system, then we should also have to suppose that the common electrons within this system have a well-defined statistical distribution. In order to disturb this it would suffice to approach this system by any molecule, the specific steric configuration of which allows it to come close enough. The basic problem was whether the protein molecule has all the qualities required for the formation of continuous energy bands, whether there is a sufficient number of atoms, or atomic groups, whether the energy-terms of these are sufficiently similar, whether they are situated sufficiently close, and, last but not least, whether their arrangement has the required high degree of regularity.

In the course of my career as a biochemist I was more and more depressed by the feeling of complete failure, not being able to explain to myself a single biological reaction. Much relieved by this new theory of matter, I gave vent to my joy in an article in *Science* entitled "Towards a New Biochemistry?" By this rather ambitious title I wanted to emphasize that the application of this new theory to living systems might mean a new period in biochemistry. The reaction to this article was rather amazing: there was none at all. The reason is evident: as long as no evidence of such band spectra in protein or living systems is produced, all this is but speculation, although P. Jordan has pointed out that certain observations of Kubovitz on enzyme inactivation were in agreement with the existence of energy bands in proteins, and Warburg and Negelein's research, together with that of Gaffron and Wohl, also showed that in chloroplasts, energy may be transmitted over a large distance. Timoféef-Ressowsky's experiments on x-ray mutation also pointed in the same direction.

My first efforts to produce fresh evidence bore no fruits and soon work had to be discontinued altogether. After the war was

over, I found myself in close proximity to P. Gombás, professor of physics, one of the pioneers of the new theory of matter, who became my faithful guide in this field. I also had Dr. K. Laki within my reach, who was partly responsible for the development of these ideas. New experiments were begun which, I think, have led to the demonstration of continuous energy bands in proteins.

II. Inner Photoelectric Effect in Protein

M. Gerendás was the first in my laboratory to try to approach the problem experimentally. He measured the dependence of electric conductivity in oriented actomyosin threads on temperature, expecting to find a Hall effect. His results were inconclusive.

J. Boros and D. König based their experiments on a research of Gudden and Völkl who, using K. W. Wagner's theory, measured the electric conductivity of dispersed semi-conductors, embedded in a dielectric. From the dielectric angular loss, the conductivity of the semi-conductor could be calculated. Boros and König tried to measure in this way the conductivity of proteins suspended in water, but the complications, introduced by the solvent, were too great. Powdered casein was embedded in paraffin, the conductivity measured, and was found to parallel the water content of the protein. On complete drying, the conductivity became too low to make the method applicable.

Having failed on this line Boros [48] was led to study the properties of gelatin phosphors.* It has been known since the end of the last century that gelatin, if dried with certain dyes and illuminated, emitted light after illumination was discontinued. The history of these gelatin phosphors is described in the paper of Frölich and Mischung. To Professor Frölich I am indebted for most of the colored gelatin films used in these experiments. The problem of these gelatin phosphors is closely related to the problem of phosphorescence in crystals. As is

*For the general theory of phosphorescence see "Luminescence, a general discussion" held by the Faraday Soc. 1938. Published by Guerney and Jackson, London (reprinted from Transactions of the Faraday Soc.)

generally known, many metal sulfides, carbides, and oxides show phosphorescence, the classical example being ZnS. On illumination, electrons are raised to a higher level, causing light absorption. When the electron falls back to the lower level, it may emit light, causing phosphorescence. There is a certain time-interval between light absorption and light emission. It was recognized that metallic impurities play a decisive role in these phenomena. (The metal may be derived from the crystal itself.) The forbidden zone between filled energy band and the next empty level is too great to allow electrons to be lifted across. The terms of the metallic impurity bridge the gap, since they lie close to the filled band. If an electron is raised by illumination to a higher level it will leave an empty place, a "hole," and the excited electron and the "hole" may travel independently, and at different speeds,* both contributing to conductivity. Eventually the "hole" and the raised electron will have to find one another, the excess energy causing light emission. This theory of phosphorescence involves energy bands. The presence of such a structure is greatly supported by the concomitant electric phenomena, phosphorescence being accompanied by an increased conductivity, the photoelectric current having the same spectral distribution as the light adsorption. This photoelectric current can hardly be explained differently except by supposing the existence of quasi-continuous energy bands.

In gelatin phosphors, the place of the metallic impurity is taken by the dyestuff. Phosphorescence is neither the property of gelatin nor that of the dyes but a property of the system formed by both. The concentration of the dye being rather low, the continuity of the system is evidently due to the gelatin. The mere fact of phosphorescence makes the presence of band-spectra highly probable but cannot in itself be taken as final evidence of such a structure. Phosphorescence can be taken as evidence of a continuous band structure if during illumination the conductivity is raised, i.e., if the electrons in a higher level can move more or less freely.

This has been demonstrated to be the case by Boros in

*Holes may move very slowly.

gelatin phosphors. He dried his colored gelatin films carefully above P_2O_5 *in vacuo*. The films were clamped between the electrodes in a small chamber, provided with a glass window, the air within the chamber being kept dry by P_2O_5. The film was illuminated with an electric arc. The current was measured with a single-threaded electrometer, by the charging method

TABLE VII. *Conductivity of Different Gelatin Phosphors in Dark and Illumination*

Dye	*Dark*		*Illuminated*
Rodulin orange	1.24	....	3.85
	1.37	....	2.75
Rhodamin B	6.65	....	32.2
	6.65	....	12.8
	13.8	....	56.5
Methylviolet 5B	12.7	....	20.7
	10.9	....	35.3
	10.9	....	16.0
	14.9	....	35.3
Methyleosin	10.9	....	45.5
	6.3	....	29.7
	9.2	....	32.6
Rhodamin 3B	8.5	....	51.7
	8.5	....	24.4
Eosin W	12.1	....	33.7
	12.1	....	17.9

with a voltage of 10–200. The whole instrument was placed in a metallic cage. Cooling of the light, by passing it through water, did not affect the results, which are summed up in Table VII. The single numbers give the average of five readings. The numbers give relative intensity of current in dark and during illumination.

The table shows that there was a considerable increase of conductivity during illumination in all experiments, ranging from 50–500%.

This internal photoelectric effect of the protein shows that the system has a band-spectrum and this structure is actually involved in its phosphorescence. This latter conclusion allows the extension of the study to watery solutions where conductivity of the solvent makes the measurement of the very weak photoelectric current impossible.

III. Phosphorescence of Chromoproteids

J. Gergely [49] undertook, as first orientation, to make observations of phosphorescence of a number of different substances. He dried their solution down with a small quantity of rodulin orange, other dyes like fuchsine, orange, and methylene blue being less satisfactory. As a beginning, the following low-molecular weight substances were tested:

*Phosphorescent**	*Non-phosphorescent*
Carbamide	Urethane
Guanidine sulphate	l-aspartic acid
Orcine	l-asparagine
Pyrocatechol	Hesperidine (from alkaline watery solution, noncrystalline)
Various sugars	Quinone (from water or alcohol)
Glycocoll	Cholesterol (from ether or chloroform)
Glutamic acid HCl	Stearic acid (from chloroform)
Hydroquinone	Resorcinol (from alkaline water, not crystalline)
Sodium acetate	α-and β-naphthols (from alkaline water, not crystalline).
Resorcinol (from alcohol, crystalline)	
α-and β-naphthols (from alcohol, crystalline)	

In solution none of these substances showed a phosphorescence, which is natural if we assume that phosphorescence is an expression of band-spectra and a rather great number of particles is needed for their formation. The table shows the well-known fact that the crystalline condition, in itself, is not sufficient for the establishment of this structure, but is still essential for its development. The intensity of phosphorescence depended on the well-formed nature of the crystals. The more perfect the crystals were, the more intense was the phosphorescence. If the dried mass was formed from a rather concentrated solution by rapid evaporation, crystals were imperfect and phosphorescence was weak. The extreme of this difference is represented in the two last members of the two columns. The same substances, resorcinol and α and β-naphthols were dried down in crystalline and amorphous conditions. In the first case they showed a strong phosphorescence, in the latter they were non-phospho-

*Schmitt (*Wied. Ann.* **58**, 102, 1896) found hippuric acid, sulpho-carbamid, anilottic acid, quinine-bisulphate and sugars to be phosphorescent.

rescent. These observations are expressions of the well-known fact that a very regular arrangement in space, such as a crystal lattice, is necessary for the formation of continuous energy levels.

As the next step, a series of proteins was dried down in like manner. They were: gelatin, casein, serum-proteins, egg-white, actin, myosin, actomyosin, fibrinogen, and fibrin. Myosin and fibrin were found previously to be fluorescent by Boros, who prepared films of them.*

All of these proteins showed an intense phosphorescence although none of them was crystalline. The protein molecule has thus in its own structure that high degree of regularity which is necessary for the development of continuous energy bands. It was this difference between proteins and other substances, giving phosphorescence only in crystalline condition, which caused physicists to call such dye-protein systems collectively "gelatin-phosphors" to distinguish them from the "crystal-phosphors."

If the dried gelatin-phosphor is moistened, it loses its phosphorescence, showing that in water either the close association of the gelatin particles or the association of the gelatin particles with the dyestuff is disturbed. This absence of phosphorescence in a watery medium is, however, not a general property of proteins. Actomyosin, for instance, in a 2% solution shows (with rodulin orange) a fairly strong fluorescence if observed in a sufficiently deep (4 mm.) layer. With 0.25 mg. dye per ml. the phosphorescence was weak, reddish-brown. On diluting the dye, the phosphorescence became stronger and was yellowish-green. It reached a maximum with 0.01–0.06 mg. dye per ml. and ceased with 0.003–0.004 mg. In observing phosphorescence, the optimal dye concentration was used and the latent period of phosphorescence was taken into account, the result being declared negative only if no light emission appeared after five minutes of illumination.

*Films were prepared by pouring the watery protein-solution on Hg in the desiccator. Fibrin films were prepared in a like manner, the thrombin being added to the fibrin solution immediately before this was poured on the Hg.

The phosphorescence in a watery solution is important because it shows that even in water, small molecules, like dyes, can enter with the protein in sufficiently intimate relation to allow the development of a common electronic structure.

The results of the first observations on different proteins were the following;

Myosin: to the crystalline mass of myosin, containing 20–40 mg. protein per ml., KCl was added to make the final concentration 0.1–0.5 M for this salt. Phosphorescence was intense, as was the DRF. Then the myosin was diluted with 0.5 M KCl. The period of latency gradually increased from 30 sec. to 4–5 min. When the myosin concentration decreased to 1%, phosphorescence and DRF disappeared. If one part of actin was now added to every five parts of myosin, the fluorescence and DRF reappeared and remained observable down to a dilution of 0.3–0.6% actomyosin. The reappearance of phosphorescence on the addition of actin is important because it shows that the lack of phosphorescence in a 1% myosin solution was not due to the low protein content but to the lack of association of these particles. (In the low concentration used, the actin itself has no phosphorescence.)

Actin showed phosphorescence and DRF in 1–2% solution.

Egg white was concentrated to half its volume. 20% protein. No DRF, phosphorescence.

Serum: 7% protein. No DRF, no phosphorescence.

Casein: below 10%. No DRF, no phosphorescence. Above 10%, both positive.

Casein is globular, myosin is slightly elongated. The axial asymmetry of neither is big enough to orient the particle in streaming fluids at moderate gradients. Their DRF is not due to the orientation of the single particles but to their loose association. This is reached with the slightly elongated myosin above 1%, and demonstrates itself in the DRF. The simultaneous appearance or disappearance of phosphorescence and DRF brings out two rather important points: (1) the single protein particle, myosin or casein, gives no phosphorescence—evidently it is not big enough to contain a sufficient number of atoms or atomic groups to make common bands; (2) even a

superficial association of particles is sufficient for the establishment of a common electronic band-structure stretching over the whole system.

If the superficial association is intimate enough to provide fusion of energy-terms then we can expect the same at a still higher degree from fibrous colloids forming the insoluble basic cellular structure. So the whole elementary fibril can be expected to form a single unit with common energy bands, whatever its length. The same can be expected to be true for structural proteins of other cells, the cell membrane denoting the probable border of the single energy-units. This may perhaps give an adequate explanation of the basic biological fact of the division of higher organisms into such small units, cells.

P. Gombás and Hofmann have calculated the stability and thereby the upper limit of the number of atoms forming such energy-units in proteins. Their results agreed closely with the number of atoms in the structural proteins of one single, average animal cell. The calculation, involving one rather fortuitous assumption, will not be reproduced here, but it is not impossible that calculations can be produced in time without any fortuitous elements, and quantum-mechanical reasons can be given for the existence and dimensions of a cell. It is remarkable that most animal cells have approximately the same dimensions. The dimensions of plant cells, protozoa, or egg cells may be very different, but it would be interesting to know whether the quantity of structural proteins in these cells is not similar to the quantity of these elements in the animal cell.

A few observations of G. Rózsa may be quoted about phosphoresence in animal organs. Their incompleteness is due to the fact that this whole line of research has been taken up very recently and there was no possibility yet for the development of more quantitative methods or the study of more extensive material. Rózsa's experiments show that animal tissues, e. g., dried muscle lamellae of rabbit's diaphragm of the abdominal wall, show an intense fluorescence in the Becquerel phosphoroscope if dyed with rodulin orange, lactoflavine, or haematoporphyrine. The most intense was the effect with rodulin orange. Hydroquinone reduced, quinone extinguished phosphorescence.

Muscles were cut on the freezing-microtome into slices and the slices dyed and dried on non-phosphorescent celluloid plates. The best results were obtained with slices 0.02–0.05 mm.

thick and dyed with a solution of rodulin orange containing 0.03–0.05 mg. of dye per ml. Slices of heart muscle, liver, kidney, brain showed phosphorescence. The wet, fresh, dyed slices showed a distinct though weaker phosphorescence.

Extraction with distilled water or treatment with different drugs, like chloroform water, digitoxin, or thyroxine seemed not to influence phosphorescence which could be observed even in organs affected by parenchymatous degeneration (heart, liver), though differences may be revealed later by more quantitative methods. Incipient *post mortem* decomposition did not seem to affect phosphorescence.

Finally, different organs were studied without any dyeing or drying. A distinct, though rather weak, yellowish phosphorescence was observed.

IV. Structural and Time Relations

It is evident that if there is a continuous band structure of energy-terms in proteins, its backbone is the polypeptide chain with its high regularity of pattern. Side chains tend to decrease the regularity of the structure. Their position is regular but their nature is different, though the atoms taking part in their construction are the same as those building the polypeptide chain.

The terms of C, N, O, and H are given in the first columns of Fig. 44, the highest filled levels being marked with a solid line, empty levels with a broken line. The filled levels of H, N, and O are rather similar and can be expected to fuse into a common band, the width and position of which are tentatively given in the fifth column. The term of C is different and could be expected to fuse rather with the first empty levels of H, N, and O into a common band, the position of which is given tentatively in the fifth column. Naturally, these are but guesses, and it might be that not the single atoms but atomic groups like CO, NH, and CH, act as unit cells, in which case the term structure will be quite different. Nor do we know to what extent the side chains take part in the common structure.

There is no reason to suppose that the short side chains, bearing the COOH groups, should remain excluded.

There is no reason to suppose, a priori, that the peptide link is the only carrier of structural continuity. The significance of H bonds has been recognized more and more in the last

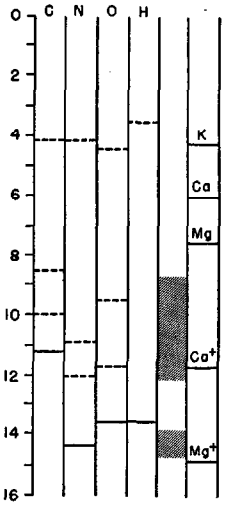

Fig. 44

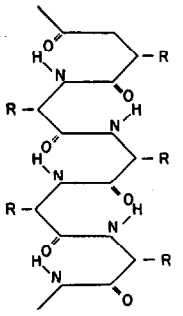

Fig. 45

decade. The supposition of H bonds between CO and NH groups of the polypeptide chain offers many new possibilities. If, for instance, we write the peptide chain in the form shown in Fig. 45, the establishment of such H bonds could transform the whole chain into a cyclic structure.* The energy of the bands is not inconsiderable, and may be in the range of 10,000–50,000 cal., which energy may contribute to the stability of the whole structure and also to the stability of the H bonds along which it extends. On the other hand the H bond, preventing rotation around C-C and C-N axis, may contribute to the spatial regularity of the structure and thereby to the establishment of common energy levels.

The extent of the continua need not be a fixed magnitude, and may depend on the state of the structure and may increase

*The H, not being directed in space, need not be counted with the members of the ring, which thus make six in number.

in the dehydrated (precipitated, contracted) state when different molecules or different parts of the same molecule come into closer contact, as has been postulated in the case of the succinoxidase.

Phosphorescence in "gelatin-phosphors" has a latent induction period which may last for several minutes. Corresponding to the latent period there is an after-effect, observed and studied by Frölich and Gyulay, which may last for hours and is demonstrated in the reduction of the latent period in repeated illumination. It looks as if we have to fill up certain energy levels with excited electrons until phosphorescence occurs, or fill up a certain level to a certain degree. As shown by the duration of the after-effect, these non-phosphorescent, excited electrons seem to be quite stable and persist in the excited condition for hours. This may have the greatest importance for biology, at the same time opening new technical possibilities. Boros had the impression that the latent period is reduced by preceding illumination not only in the illuminated spot but also in its vicinity. If this is borne out by quantitative measurement, it means that this "basic excitation" spreads and that the excited electrons move away by measurable distances. This may open the way to the study of the spontaneous motion of electrons along different structures, such as the muscle or nerve fibrils, and their arrest by formations like cell membranes, etc.

V. Biological Aspects

It may be objected that there is no point in discussing biological implications until the energy levels of the protein are known. Certainly the knowledge of the term structure is of basic importance, and this only can bring biological problems into the realm of quantum mechanics. Meanwhile, the general consequences of a band structure can be considered and may even lead to new experiments. As will be found by those who try to apply this theory of continuous band spectra to biological problems, the first result of this application is a freedom of thought which allows an approach to problems that seemed

beyond reach before. With the continuum theory in the back of one's mind, most of the biological problems appear in a new light. One might be in danger of being carried away by fantasy but there is no reason, even at the price of this danger, not to review biological problems in the light of this theory. I shall try to limit myself on this subject to a few problems which have occupied my mind in the past a great deal and with little result.

The problem of the oxidation of succinate has already been discussed. The electrons, released from the H of succinate by the succinodehydrogenase, must pass the cytochromes of Keilin before reaching oxygen. By passing from one cytochrome to the other, the electrons gradually lose their energy, as indicated by the decreasing redox potential of the cytochrome series. The redox potentials of the single members of this system lie about 200 mv. apart, dividing the drop of energy into four more or less equal parts. The single cytochromes are fixed in space, being linked to the insoluble structure. My difficulty with these cytochromes always was that I could never understand how they could react at all. According to classical chemical concepts their Fe atoms would have to collide in order to react. It is almost impossible to place three such big atomic structures in space in such a way that their Fe atoms should touch. They would have to touch not only each other, but also the metal of the cytochrome oxidase and the active group of the succinodehydrogenase as well. But if we managed to arrange these substances in this required position then the whole system would make no sense, for the shooting of the electron through this series would represent a chain of spontaneous reactions the energy of which would be liberated as heat and lost as a source of work. The continuum theory offers a simple explanation. In this theory the Fe atoms of the single cytochromes play the same role as of the "metallic impurity" in phosphorescence, which allows excited electrons of higher energy levels to drop to lower levels. One would have to picture each Fe atom as being coördinated to a certain energy level. The electron of the H of succinate is placed by the succinodehydrogenase on the highest of these levels which electron

would have to move there until it finds a cytochrome-Fe codiörnated to this level, which allows it to drop to the next lower level. Here it would have to find its next cytochrome-Fe and so forth. It is easy to believe too that these single cytochromes represent mechanisms which allow the energy, given up by the dropping electron, to be employed usefully. The question whether these supposed energy levels are empty levels of the protein, or are levels of the cytochrome system (formed in analogy to the energy continuum found in chlorophyl) must be left open. The latter possibility seems more probable; if the energy levels of protein would not lie further apart than by 200 mv. (as is the case with cytochromes) then thermal agitation would suffice to raise electrons from lower to higher levels and proteins would have to be colored, as are the cytochromes, if they have their extra electron.

In this picture the real sense of oxidation is to place excited, energy-rich electrons on the "structure" which performs the basic biological functions. The real food of this system is the excited electron. Since the whole living unit, the cell, bacterial or virus body, forms one energy unit, it is immaterial where we feed in the H or electron, at the head or at the tail end. The highest degree of symbiosis would be that where one organism is devoid of the whole metabolic apparatus and feeds simply by touching upon another living structure, taking its excited electrons. Possibly this highest degree of parasitism is found in viruses.*

There is one sort of cell in the animal body which has no access to blood or lymph: the outer cells of multilayered epithelium. These cells could thus be expected to feed on excited electrons of deeper cells. Accordingly, this is the only animal tissue (to my knowledge) in which the cell membranes are broken through by bridges.

Naturally, one could explain this by supposing that the connections serve as channels for the cell fluid. The former assumption, however, is supported by the rather mysterious behavior of hairs (a form of multilayered epithelium) the condition of which depends on the animal's health, though they have no circulation, and cell fluids cannot be expected to diffuse at such

*In many ways certain viruses, like tobacco mosaic virus, resemble the fibrous structural proteins. If the myosin particle were stripped of its whole metabolic apparatus and if the remaining frame liberated itself from the rules of its community, retaining its reproducibility, it would behave as a virus.

distances in an anhydrous system. The appearance of the hair changes in a short time if the animal is taken ill, its shininess disappearing; this is a truer indicator of the animal's health than the thermometer. According to the experience of hairdressers, permanent waves do not hold if made during the menstrual period. The change sets in one day before bleeding starts. L. Varga has tried to measure these differences between menstrual and intermenstrual hair by physical methods measuring extensibility, strength, and torsion modulus. Hitherto these methods have been inadequate. One would be inclined to connect these observations with the latent induction period of phosphorescence which suggests that there may be in protein stable electrons in a lower degree of excitation, and one may even start speculation about the relation of health to the degree of saturation of these energy levels.

The common electron bands of the protein particle may make the peptide links inaccessible to enzymes, which might explain the resistance of native globular proteins to trypsin. The connection of the band structure with the native state may explain the all-or-none nature of denaturation. Once a band breaks down and rearrangement takes place, this denaturation must be complete, exposing at the same time the peptide link to the attack of enzymes. The higher the energy level of the bands, and the more electrons these bands contain, the more complete may be their protecting action against trypsin or bacterial enzymes.

The continuum theory allows us to consider ideas as abstruse as those of health and disease, but it may take us even one step further into mysterious domains like that of the origin of life. It is not impossible that the gelatin phosphor, a chromoproteid, represents the simplest form of life in which energy of radiation is made accessible to the protein by a dyestuff. Flavins and probably fluochromes and cytochromes are capable of acting this way. The present-day participation of these dyes in metabolic processes may be the continuation of this ancient function, with the difference that it is not radiation but metabolic energy which they transfer onto the protein.